METHODS OF OBTAINING GROUND WATER

Many types of wells are used in the Jackson Purchase. The type of well and casing is determined by the depth to water, the quantity of water desired, and the availability of funds. In the past, most wells were dug or augered by hand, but in recent years most wells have been drilled by machine. Hand-dug wells rarely exceed 60 feet in depth. Most dug wells are lined with brick or concrete tile; most hand-augered wells are cased with terra cotta tile. Neither the brick nor the tile offers a watertight seal, and therefore wells lined with these materials are liable to pollution from surface sources.

Large industrial and municipal wells are usually drilled by the hydraulic rotary process. In this method, a toothed bit is mounted on the end of a string of drill pipe. The pipe is rotated by machinery so that the bit cuts through the rock. During drilling, a "drilling-mud" consisting of a suspension of natural clay or artificially prepared constituents is pumped down the drill pipe and through holes in the bit. It then flows back up to the surface in the annular space between the drill pipe and the cylindrical walls of the hole. The drilling mud carries the rock cuttings to the surface, seals off porous formations to prevent the loss of drilling fluid, and exerts a hydrostatic force which prevents the walls of the hole from collapsing. In this way uncased holes can be drilled to great depths.

Many small-diameter domestic wells are drilled in unconsolidated material by the jetting process. In drilling by this method, a jet of water is forced against the formations through a small-diameter galvanized pipe. The pipe is rotated to aid the cutting action of the jet of water and to keep the hole straight. Additional lengths are attached as the hole is deepened. When water-bearing material is penetrated, a well screen is dropped through the pipe to the bottom of the hole. The jetting pipe thus serves also as well casing and pump column in wells drilled by this method. Wells can be jetted to depths of about 200 feet.

Cable-tool machines are used to drill in both consolidated rocks and unconsolidated deposits. This type of rig has a steel drill bit on the end of a rope or wire cable. By means of a motor-driven eccentric action, the bit is raised and then dropped against the rocks. The chisel-shaped bit cuts the rock in much the same way as does a masonry, star drill. When several feet of rock has been broken by the drill, the bit is hoisted from the hole and the debris removed with a bailer—a piece of thin-walled pipe having a flap valve in the bottom. Wells in unconsolidated rocks are drilled through casing, and the casing is periodically driven down so as to stay within a few feet of the tip of the drill bit.

Along the flood plains of the larger rivers, many hand-driven wells are used. These wells are installed by hammering down a small-diameter pipe into the alluvium. The lower end of the pipe is fitted with a well point and strainer. Driven wells are usually equipped with pitcher pumps; however, some of larger yield are pumped with small electric pumps.

In areas of unconsolidated deposits where the depth to water is less than about 100 feet, boring rigs (mechanical augers) can be used. These machines rotate a cylinder or bottomless bucket on the end of a steel shaft. As the shaft is rotated, blades at the bottom cut into the sediments and fill the bucket. The shaft and bucket are then lifted from the hole by a windlass, and the bucket is emptied. Boring rigs can penetrate but a short distance below the water table in certain loosely consolidated sediments. Bored wells are usually lines with concrete tiles. The tiles should be made watertight at each joint to prevent pollution from surface seepage.

The pumping equipment used in the Jackson Purchase depends on the depth to water, the type and yield of the well, and the quantity of water needed. Where the depth to water is less than 25 feet, as in some of the areas underlain by gravel of Pliocene(?) age and along the flood plains of the large rivers, wells can be pumped by hand pitcher pumps and by motor-driven cylindrical or centrifugal suction pumps. Most domestic wells in which the depth to water is greater than 25 feet use jet pumps or submerged-cylinder lift pumps. In some areas water is obtained from both dug and drilled wells with hand-operated buckets or bailers.

For yields greater than about 20 gpm, submersible or shaft-driven deep-well turbine pumps are used. Most industrial and municipal wells are equipped with such pumps. The shaft-driven pump consists of a submerged centrifugal pump unit connected to a motor at the surface by a vertical shaft. The submersible pump is similar, except that the motor is beneath and directly coupled to the pump, forming a single submerged unit suspended at the bottom of the discharge pipe.

Wells that bottom is unconsolidated sediments, except those of small yield in fairly coarse sand or gravel, require some form of screen or strainer to keep sand out of the well. For most domestic wells it is enough to install the screen and pump the well until the water clears. For large-capacity wells this procedure may not be satisfactory. The screen of large wells are selected so that the smaller particles of sand around the well will pass through the slots and be pumped out, in a process called developing the well. After the screen is installed, the well may be surged by forcing water into and out of the aquifer to wash the fines into the well. The fines are periodically removed during the surging process. The surging is accomplished by raising and lowering a piston within the casing, by alternately pressurizing and then relieving the pressure in the well by means of compressed air, or by intermittent pumping at a high rate. Large-capacity wells may be constructed with a gravel envelope around the screen which increases the effective size of the well.

OCCURRENCE OF GROUND WATER

PALEOZOIC

Limestone and chert of the Mississippian system crop out or lie at shallow depth in a narrow belt along Kentucky Lake. The oldest of these rocks that is of importance as an aquifer is the Fort Payne chert. The outcrop area is long and narrow, the chert being exposed on ridges and spurs and, in some places, on the lake shore. The Fort Payne consists of interbedded limestone and chert, but solution of the limestone to great depths has caused sagging, compaction, and fracturing of the chert bed. In some places all the carbonate minerals in the limestone have been removed, leaving a rubble of loose chert in a clayey matrix. The material is similar to an unconsolidated deposit in that wells require a casing and a perforated pipe or screen in the water-bearing zone. Ground water is transmitted in fractures in the chert and in solution openings in the limestone. Most small-diameter wells yield enough water for a modern domestic supply; one public-supply well at Kentucky Lake State Park, 10 inches in diameter and 175 feet deep, produces at the rate of 62 gpm. In some areas the Fort Payne contains residual clay or tripolitic material which clogs well screens. The Fort Payne is an important source of water to the many cottages, fishing camps, and resorts along Kentucky Lake.

Samples of water from 1 spring and 4 wells in the Fort Payne were collected for chemical analysis. Three of these samples were soft, one was hard, and one was very hard. The water is of the calcium magnesium bicarbonate type.

In western Ballard County in Kentucky and in Alexander and Pulaski Counties in Illinois, chert of Devonian and Mississippian age lies beneath the Ripley formation and river alluvium and contains water under artesian pressure. Wells drilled into these cherts flow with heads of 6 feet or more above ground level. The municipal well at Mound City, Ill., flowed 85,000 gpd (gallons per day) when it was first drilled. Several wells drilled in and near Cairo, Ill., have penetrated this chert zone. A well at the Halliday Estate is reported to have flowed an estimated half a million gallons per day when it was drilled in 1898 (Glenn, 1906).

The Warsaw limestone, exposed at only a few places south of Kentucky Dam, is of small importance as an aquifer. The water from the Warsaw is reported to be moderately hard and apparently can be obtained in quantities sufficient for a modern domestic supply.

Two wells obtain water from the St. Louis limestone. One well is near Gilbertsville and the other is at Calvert City. The St. Louis crops out in a narrow belt in the area extending from Kentucky Dam to Calvert City. In exposures the St. Louis exhibits solutionally enlarged joints and cracks, and it is these openings that transmit the water. One well at Calvert City produces 26 gpm from this limestone. The well is 6 inches in diameter and 375 feet deep. Water from this well has a hardness of 188 ppm and is of the calcium magnesium bicarbonate type. Water from the St. Louis is suitable for household purposes but would have to be treated for many industrial applications.

In the outcrop area of Mississippian rocks, most wells will yield sufficient water for a modern domestic supply, and some will yield enough for a small public supply (fig. 14). The 1-hour specific capacity of a well in Mississippian bedrock in McCracken County was 1.5 gpm per foot. (See fig. 16.)

The water in the bedrock of the Jackson Purchase differs in quality from that in the rest of Kentucky in one important respect. Connate salt and sulfur (hydrogen sulfide-bearing) water are uncommon in the Paleozoic rocks of the Purchase, even at depths as great as 3,000 feet. Fresh water reportedly has been found in the Ordovician and Silurian rocks at depth in several oil tests. This fact indicates that ground-water circulation is active at very great depths in the consolidated rocks underlying the Purchase.

CRETACEOUS

The Tuscaloosa formation is of minor importance as an aquifer in the Purchase, owing to its thinness and small area of outcrop. In some places this formation contains a clayey matrix which plugs well screens and makes the water turbid. The two wells tested yield soft water moderately high in sulfate and chloride content.

The Ripley formation is an important aquifer in Calloway, Marshall, McCracken, and Ballard Counties. It supplies many shallow wells in its outcrop area and many deep wells where the thickness of overlying beds is 500 feet or less. The Ripley, where present, is a good source of water in Calloway and Marshall Counties. The Ripley also supplies water to wells in much of McCracken County and the northern half of Ballard County. In Graves, Hickman, Carlisle, and Fulton Counties the Ripley lies too deep for economical water production under present conditions, but adequate supplies may be obtained from shallower aquifers in most places. The isopach map, figure 17, shows the variation in thickness of the Ripley formation in the Purchase. The formation ranges from 0 to 400 feet in thickness. The contours on the top of the Paleozoic bedrock (bottom of the Cretaceous), figure 17, show minor troughs superimposed on the major bedrock trough which underlies the whole of the embayment area. These minor depressions contain fillings of the Ripley, whereas the intertrough areas have only a thin cover of the formation. The Ripley changes in facies along its southeast-northwest strike. From Hazel to approximately a mile north of Murray in Calloway County, sand makes up the bulk of the formation. From this point northward, the amount of silt and clay increases until at Benton, Marshall County, the formation is composed mostly of silt and clay, there being only 25 or 30 feet of sand at the base. The amount of sand then increases from Benton to Sharpe and the McCracken County line. Under most of McCracken County the Ripley consists mostly of clay and silt, there being 25 feet or less of fine to medium sand at the base. From western McCracken County to Ballard County and thence to Dam 53 in Illinois, the amount of sand increases again. The facies changes affect the availability of water in the Ripley formation in accordance with the amount of sand in the formation. Little or no water can be obtained in areas where the formation is predominantly silt and clay, as in southern McCracken County. Large quantities of water are obtained from the formation where it is mostly sand. At Murray a city well has a measured yield of 831 gpm with a 31-foot drawdown after approximately 2 hours of pumping. (See fig. 18.) The well is 255 feet deep and penetrates 60 feet of sand in the Ripley formation; it is fitted with 50 feet of 10-inch screen. Although the two city wells at Benton penetrate only 25 feet of sand beneath 156 of clay, each produces 250 gpm. A similar situation exists at Reidland, where the new city well is screened in 26 feet of sand of the Ripley above the Paleozoic bedrock. This well is pumped at 150 gpm with a drawdown of 179 feet.

Table 3.—Hydrologic characteristics of geologic formations in the Jackson Purchase region, Kentucky
[Sample: H, horizontal; V, vertical]

Sample	Location	Geologic unit	Moisture content (percent, by dry weight)	Coefficient of permeability (gpd per sq/ft)	Average unit weight of solid constituents (gr per cc)	Unit weight of dry sample (gr per cc)	Porosity (percent, by volume)	Specific retention (percent, by volume)	Specific yield (percent, by volume)
1 V	6 miles west-northwest of Barlow, Ballard County	Quaternary (alluvium)	10.7	480	2.62	1.28	51.1	5.7	45.4
1 H	do	do	10.3	460	2.68	1.30	51.5	5.7	45.8
2 V	3 miles northwest of Oscar, Ballard County	do	10.8	300	2.68	1.42	47.0	7.1	39.9
2 H	do	do	9.6	240	2.67	1.45	45.7	6.7	39.0
3 V	2 miles south-southwest of Columbus, Hickman County	Pleistocene (loess)	23.8	6.1	2.74	1.39	49.3	16.2	33.1
3 H	do	do	20.7	4.1	2.74	1.35	50.7	16.0	34.7
4 V	0.5 mile south of Wickliffe, Ballard County	do	18.7	2	--	1.50	44.4	--	--
5 V	2.5 miles south of Lone Oak, McCracken County	Eocene (sand)	7.0	160	--	1.72	35.6	--	--
5 H	do	do	7.8	54	--	1.62	39.8	--	--
6 V	2.5 miles northwest of Melber, McCracken County	do	4.7	580	--	1.39	47.7	--	--
6 H	do	do	5.5	560	--	1.40	47.8	--	--
7 H	1 mile east-northeast of Pryorsburg, Graves County	Eocene (clay)	34.5	.0003	--	1.37	48.5	44.9	3.6
8 V	2 miles southeast of New Providence, Calloway County	Eocene (sand)	6.2	700	--	1.55	41.7	3.4	38.3
8 H	do	do	3.9	1,000	--	1.59	40.2	2.6	37.6
9 V	3.5 miles west-northwest of Kirksey, Calloway County	do	8.1	230	--	1.52	43.5	1.0	42.5
9 H	do	do	8.1	400	--	1.48	44.6	1.0	43.6
10 V	5 miles northwest of Wingo, Graves County	do	8.1	170	--	1.52	42.6	1.4	41.2
10 H	do	do	8.0	270	--	1.50	43.6	2.7	40.9
11 V	2 miles south-southwest of New Providence, Calloway County	Paleocene (Porters Creek clay)	47.7	.0004	--	1.18	56.9	32.3	24.6
12 V	1.5 miles southwest of Briensburg, Marshall County	do	30.0	.0003	--	1.49	43.6	12.6	31.0
13 V	0.5 mile south-southeast of New Concord, Calloway County	Cretaceous (Ripley formation)	4.7	320	--	1.51	43.4	--	--
13 H	do	do	3.0	780	--	1.45	45.7	--	--
14 V	4 miles west-southwest of Aurora, Marshall County	do	3.6	380	--	1.53	42.5	--	--
14 H	do	do	3.7	600	--	1.43	46.4	--	--

Horizontal and vertical samples were taken from two exposures of the Ripley for laboratory tests. The vertical coefficients of permeability, in meinzers (gallons per day per square foot at 60°F) were 320 and 380, and the horizontal coefficients were 780 and 600. These differences in permeability indicate that water will move horizontally (along the bedding) at a rate about 1½ to 2½ times as great as it will vertically (across the bedding). The porosity of 4 specimens of the sand of the Ripley ranged from 42.5 to 46.4 percent. Detailed information on the mechanical analyses of the samples of the Ripley appears in table 3 and figure 19.

The water levels in wells in the Ripley near Kentucky Lake are as much as 100 feet higher than the lake surface. Figure 20, the hydrograph of a well at Murray, about 9 miles from the lake, shows a general rise in water level throughout the period of record beginning in 1950. The water rose 4 feet between 1948 and 1954. This rise in water level may be due in part to the rise of the water level in the lake. In the area immediately west of Kentucky Lake, water discharges from the Ripley formation into the lake. The ground-water divide probably was farther west before the dam was built, and the rise in head in the discharge area resulted in an eastward shift of the ground-water divide.

Flowing wells are reported in the Ripley formation in Illinois along the Ohio and Mississippi River valleys and in Missouri along the Mississippi River valley southeast of Crowleys Ridge. Grohskopf (1955) reported that most wells in the Ripley will flow if the surface altitude is less than 300 feet and the well is properly constructed. He reported flows from this aquifer ranging from 16 to 720 gpm. The source of water flowing at a rate of half a gallon per minute from a well at the southern city limits of Wickcliffe, Ky., is probably the Ripley formation at a depth of 600 feet.

Although the quantity of water available from the Ripley formation differs from place to place, most wells will yield sufficient water for domestic purposes. Wells can be drilled as deep in the formation as necessary without danger of contamination by salt or sulfur water. Except for that in the outcrop area, the water in the Ripley formation is under artesian pressure. In most places the water rises to an altitude ranging between 300 and 315 feet.

Water samples from 29 wells in the Ripley formation were analyzed. Of these, 12 were soft, 10 were moderately hard, and 5 were hard. Hardness was not determined for samples from 2 wells. The dissolved-solids content ranged from 62 to 275 ppm. The pH ranged from 6.2 to 7.9; for most samples it was slightly greater than 7.0. The iron content of the water is generally high, and many samples had more than 0.3 ppm, the limit recommended by the U.S. Public Health Service for culinary and drinking water. One sample had 15 ppm of iron. The silica content of the samples ranged from 4.6 to 34 ppm. Both iron and silica appear to be related to the depth of the well; water from most wells more than 250 feet deep has relatively high concentrations of both iron and silica. Water from this formation is suitable for household uses and many industrial applications. The main objectionable features of the water, locally, are the high iron content and the low pH. The water is of the calcium bicarbonate type.

TERTIARY

PALEOCENE

Except in a few places where wells may get water from joints or thin sand seams, the Porters Creek clay is non-water-yielding. This geologic unit is important in the hydrology of the Jackson Purchase because it is relatively impermeable and therefore inhibits the passage of water from either above or below. The hydrologic properties and mechanical analyses of samples of this clay are given in table 3 and figure 21.

Although the Porters Creek clay is relatively impermeable in comparison to the sands above and below it, some water leaks through the clay. In the northeastern part of the Eocene outcrop the hydraulic head in the Eocene sands above the Porters Creek probably ranges from 0 to 100 feet above the hydraulic head in the Ripley formation below the clay. If the average head in the Eocene in this area is assumed to be 50 feet above the head in the Ripley, and if the thickness of the Porters Creek is 160 feet, the leakage from the Eocene through the Porters Creek clay to the Ripley per square mile per day can be computed. Using the formula $Q=PIA$, where the following values are substituted:

Q = quantity of water discharged in unit time, in gallons per day.
$P=0.0004=4\times10^{-4}$ gpd per sq ft = coefficient of permeability of the more permeable of two vertical samples of the Porters Creek clay, from laboratory permeability tests.
$I=h/l$ = head divided by the thickness of material traversed = 50/160.
A = cross-sectional area through which water must flow = 1 square mile = 2.8×10^{7} sq ft.

then

$$Q=4\times10^{-4}\times50/160\times2.8\times10^{7}.$$
$$=4\times10^{3}.$$
$$=4{,}000 \text{ gpd per sq mi.}$$

The quantity of water that moves through the joints and sand beds is greater than the amount that moves directly through clay of the type tested; therefore the average leakage per square mile probably is greater than computed.

The chances of obtaining even a moderate yield from wells in the Porters Creek clay are poor. Moderate yields can be obtained in the outcrop area of the Porters Creek by drilling through the clay into a water-bearing sand in the Ripley formation. In most places where the Porters Creek is beneath the surface, water may also be obtained in overlying gravel of Pliocene(?) age or from Quaternary alluvium. Figure 22 is a combined structure and isopach map of the Porters Creek clay. The structure contours are drawn on top of the Ripley formation.

EOCENE

The Eocene series is the principal aquifer in Fulton, Hickman, Carlisle, and Graves Counties. It underlies half of McCracken County and approximately three-fourths of Ballard County also. This aquifer supplies most of the ground water in the region south and west of the outcrop of the Porters Creek clay. The depth to the water-bearing horizon becomes greater down the dip to the southwest. Although the deepest domestic wells usually do not exceed 350 feet, some public and industrial wells are more than 600 feet deep. The combined structure and isopach map, figure 23, shows that the thickness of the Eocene series increases gradually to the southwest and is greatest in Fulton County south of Hickman. Figure 24 is a contour map on the top of the Eocene series. In areas where the Eocene is composed mostly of clay, it is difficult to get a good well. The log of a well near Barkley Field, west of Paducah, shows that 114 of the 140 feet of the Eocene is clay. A well 4 miles south of Lone Oak penetrated mostly clay to a depth of 210 feet, and it is reported that a well 4 miles southwest of Hickman penetrated more than 250 feet of clay before entering a water-bearing sand. Large-capacity wells can be made in the Eocene if enough saturated sand is penetrated. Many of the wells at Fulton that have yields of 1,000 gpm are more than 500 feet deep. It is necessary to drill to this depth to penetrate enough saturated sand for such a large yield.

The Eocene series is generally a better aquifer than the Ripley formation. Except for the wells in Fulton, Fulton County, most wells in the Eocene series are shallower and have higher yields than those in the Ripley formation. The largest capacity well in the Eocene series is a public-supply well at Mayfield, Graves County. This 260-foot well had a 64-foot drawdown at a discharge of 1,700 gpm during a 2-hour specific-capacity test. (See fig. 25.) The public-supply well at Fulton had a measured discharge of 1,240 gpm and a 36-foot drawdown after 2 hours of pumping. (See fig 26.) This well in the Eocene series is 425 feet deep. Barlow, Clinton, Bardwell, Arlington, and other small towns obtain water from wells equipped with pumps which have capacities less than 300 gpm. The maximum possible yield of some of the wells may be greater than the capacities of the pumps.

Horizontal and vertical samples of sand were taken from six exposures of the Eocene series for mechanical analyses. The coefficients of permeability, in meinzers, of the vertical samples ranged from 160 to 700, and of the horizonal samples, from 54 to 1,000.

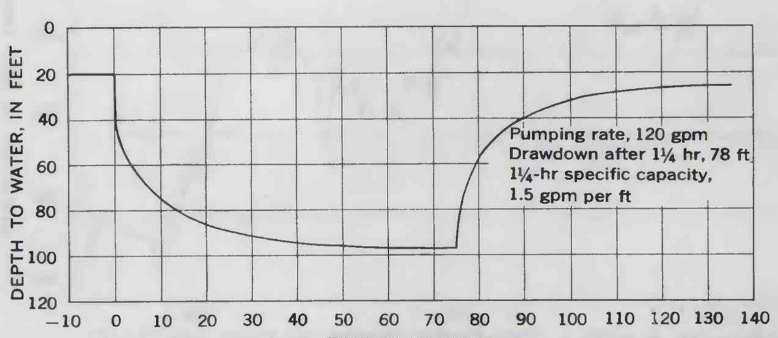

FIGURE 16—SPECIFIC-CAPACITY TEST OF A WELL 310 FEET DEEP IN PALEOZOIC BEDROCK, MC CRACKEN COUNTY, KENTUCKY

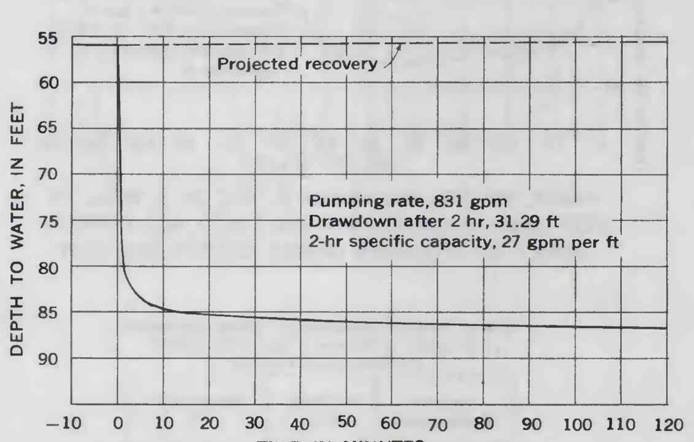

FIGURE 18—SPECIFIC-CAPACITY TEST OF A MUNICIPAL WELL 255 FEET DEEP IN THE RIPLEY FORMATION, MURRAY, CALLOWAY COUNTY, KENTUCKY

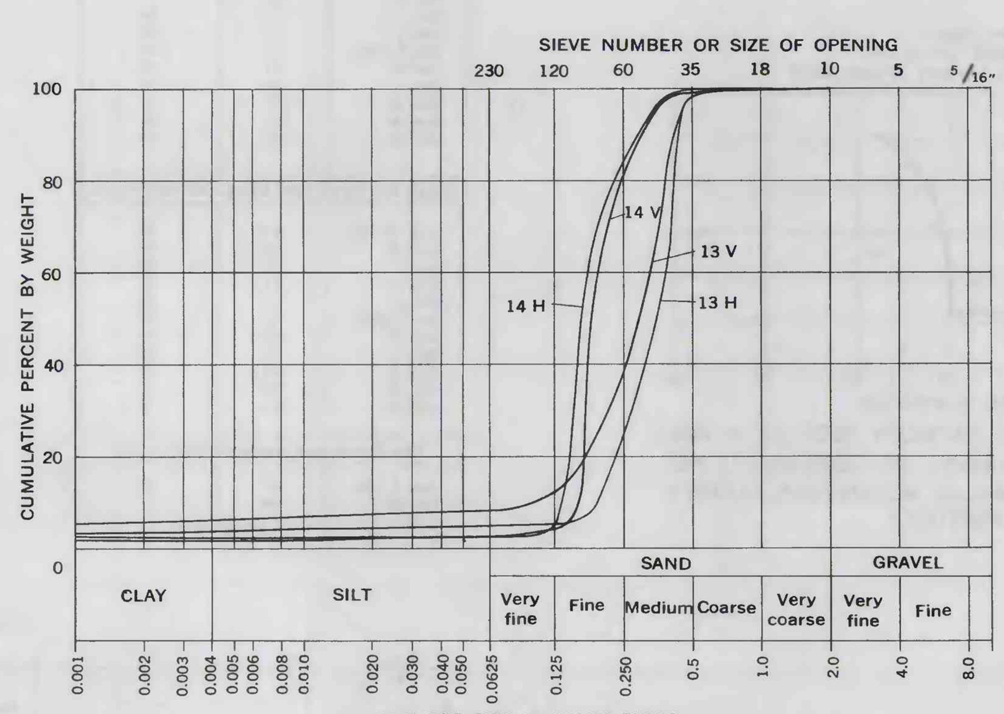

FIGURE 19—PARTICLE-SIZE DISTRIBUTION OF SAMPLES 13 AND 14 OF THE RIPLEY FORMATION

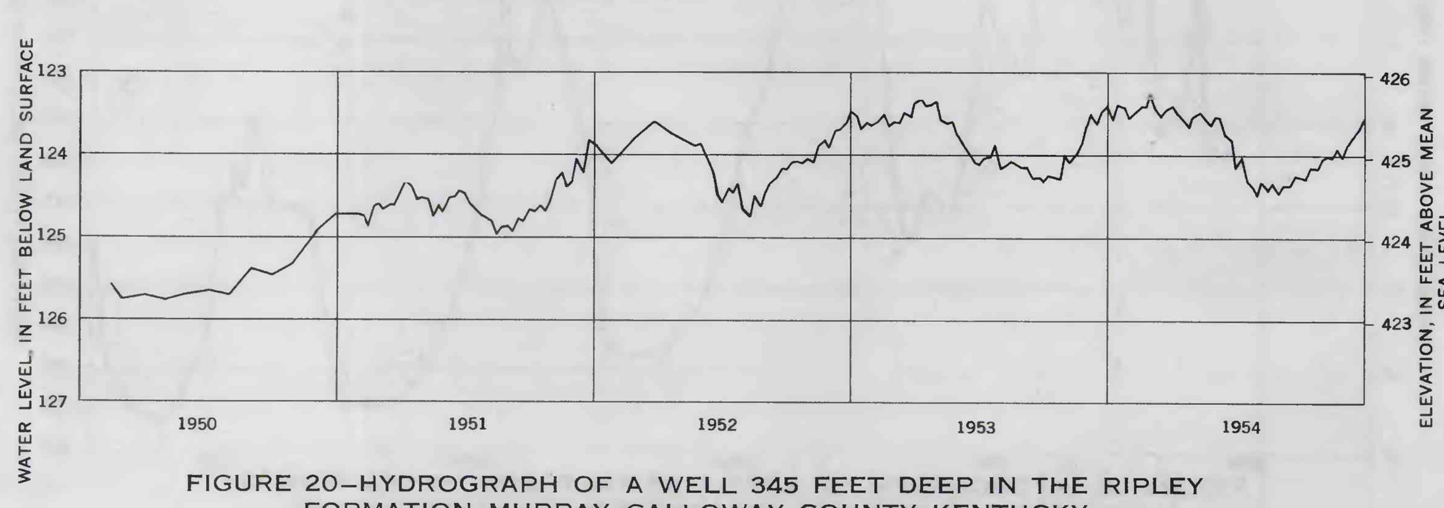

FIGURE 20—HYDROGRAPH OF A WELL 345 FEET DEEP IN THE RIPLEY FORMATION, MURRAY, CALLOWAY COUNTY, KENTUCKY

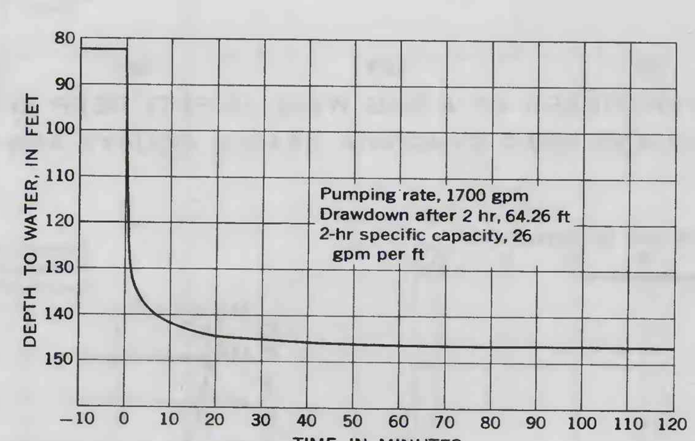

FIGURE 25—SPECIFIC-CAPACITY TEST OF A MUNICIPAL WELL 260 FEET DEEP IN THE EOCENE SERIES, MAYFIELD, GRAVES COUNTY, KENTUCKY

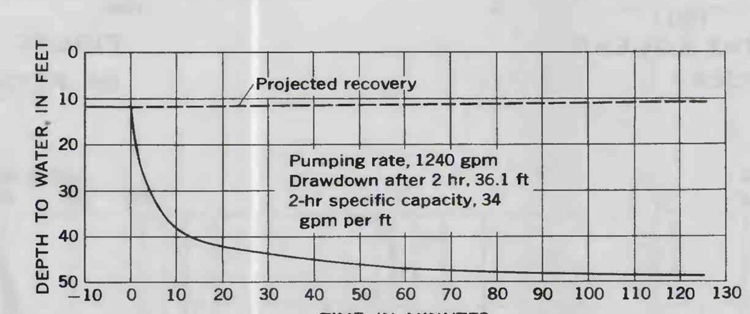

FIGURE 26—SPECIFIC-CAPACITY TEST OF A MUNICIPAL WELL 425 FEET DEEP IN THE EOCENE SERIES, FULTON, FULTON COUNTY, KENTUCKY

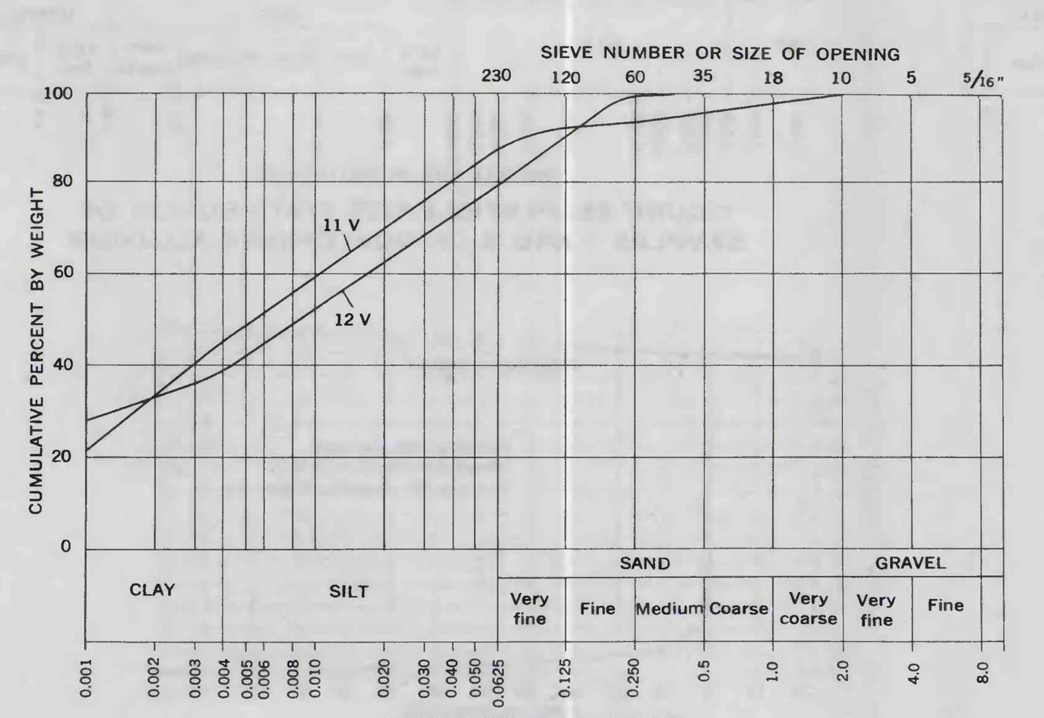

FIGURE 21—PARTICLE-SIZE DISTRIBUTION OF SAMPLES 11 AND 12 OF THE PORTERS CREEK CLAY